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NASA's Space Launch System: An Enabling Capability for International Exploration

Stephen D. Creech, Todd A. May, and Kimberly F. Robinson

Assistant Program Manager – Strategy and Partnerships, NASA's Space Launch System Program,

Marshall Space Flight Center, AL 35812, 256-544-9365, Stephen.D.Creech@nasa.gov

Manager, NASA's Space Launch System Program,

NASA Marshall Space Flight Center, Alabama, 35812, U.S.A., 256-544-1484, todd.may@nasa.gov

Strategic Communications Manager, NASA's Space Launch System Program,

NASA Marshall Space Flight Center, Alabama, 35812, U.S.A., 256-544-5182, kimberly.f.robinson@nasa.gov

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Abstract

As the program moves out of the formulation phase and into implementation, work is well underway on NASA's new Space Launch System, the world's most powerful launch vehicle, which will enable a new era of human exploration of deep space. As assembly and testing of the rocket is taking place at numerous sites around the United States, mission planners within NASA and at the agency's international partners continue to evaluate utilization opportunities for this ground-breaking capability. Developed with the goals of safety, affordability, and sustainability in mind, the SLS rocket will launch the Orion Multi-Purpose Crew Vehicle (MPCV), equipment, supplies, and major science missions for exploration and discovery.

NASA is developing this new capability in an austere economic climate, a fact which has inspired the SLS team to find innovative solutions to the challenges of designing, developing, fielding, and operating the largest rocket in history, via a path that will deliver an initial 70 metric ton (t) capability in December 2017 and then continuing through an incremental evolutionary strategy to reach a full capability greater than 130 t. SLS will be enabling for the first missions of human exploration beyond low Earth in almost half a century, and from its first crewed flight will be able to carry humans farther into space than they have ever voyaged before.

In planning for the future of exploration, the International Space Exploration Coordination Group, representing 12 of the world's space agencies, has created the Global Exploration Roadmap, which outlines paths toward a human landing on Mars, beginning with capability-demonstrating missions to the Moon or an asteroid. The Roadmap and corresponding NASA research outline the requirements for reference missions for these destinations. SLS will offer a robust way to transport international crews and the air, water, food, and equipment they would need for such missions.

I. BACKGROUND

When United States President John F. Kennedy announced in 1961 a national goal to land humans on the Moon by the end of the decade and bring them safely home, the country had only minutes of spaceflight experience from one suborbital flight. In order to meet that goal, a variety of new capabilities would have to be developed to bridge the gap between from that one suborbital flight and a lunar landing. Over the course of the next eight years, NASA would incrementally develop, test, and demonstrate those capabilities, including such things as weeks-duration spaceflight, rendezvous and docking, and extravehicular activities. By gradually increasing capabilities and reducing risk, the agency was able to accomplish the goal of a lunar landing by Kennedy's deadline.

Today, members of the international spaceflight community have identified Mars as the next significant goal for human space exploration, and have begun identifying a cooperative roadmap to address the incremental steps that will be necessary to accomplish that goal. The process of enabling a human landing on Mars from the present status of human spaceflight will present challenges and require new developments that will dwarf those necessary to reach the Moon when Kennedy first announced his goal. Numerous new systems will be required – in-space propulsion, in-space and surface habitation, in-space and surface power generation, landers, and surface operations equipment, at a minimum. As these systems are being developed, it will be possible to conduct incremental human exploration

missions into deep space to test and demonstrate the needed capabilities, as was done leading up to the Apollo moon landings. Together, the systems needed for a human Mars mission will be massive, most likely substantially greater mass than the International Space Station, and placing those assets in space in order to conduct the mission will require massive space launch capability. NASA is building its new Space Launch System to be the vehicle that will enable human missions to Mars, and the rocket offers the capability to serve as a cornerstone of a new era of international exploration of deep space.

Scheduled for a first launch in 2017, the NASA Space Launch System (Fig. I) will serve as a new national infrastructure asset that will open up the solar system for human deep-space exploration, while providing enabling benefits for a wide variety of other missions. Since the NASA Authorization Act of 2010 mandated the development of a heavy lift vehicle [1], rapid progress has been made on the world's first exploration-class launch vehicle since the Saturn V, designed to carry human beings beyond LEO for the first time since 1972, when the Apollo Program concluded its sixth and final landing on the Moon.



Fig. I. Artist's concept of SLS and Orion in the KSC Vehicle Assembly Building.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion Multi-Purpose Crew Vehicle (MPCV) Program and the Ground Systems Development and Operations (GSDO) Program. The Orion MPCV is a four-person spacecraft designed to carry astronauts on exploration missions into deep space. GSDO is converting the facilities at NASA's Kennedy Space Center (KSC) into a next-generation spaceport capable of supporting launches by multiple types of vehicles. These capabilities are part of a larger NASA strategy of working with commercial partners that will support crew and cargo launches to the International Space Station, while the Agency focuses its development efforts on blazing new trails via an incremental approach to developing systems necessary for human exploration beyond Earth orbit and eventually to Mars, an approach that presents substantial opportunities for international cooperation. Both Orion and SLS are being designed with enough performance margin and flexibility to support multiple missions and destinations rather than being limited to one particular mission or architecture.

Following the successful first flight of SLS, the vehicle will undergo block upgrades to an eventual full capability of delivering 130 t to LEO, making it the most powerful launch vehicle ever flown. This evolved configuration, baselined around NASA's Mars Design Reference Architecture studies, is designed to meet the requirements necessary to enable a human mission to Mars. Work is currently underway to do initial engineering studies and risk reduction work to support the evolution of the vehicle.

II. VEHICLE OVERVIEW

Space Launch System is designed to take advantage of NASA's heritage of success in human spaceflight, updated for a new era of exploration (Fig. II). The NASA Authorization Act of 2010 laid out requirements for a powerful, versatile transportation system that could support a range of strategically important missions. NASA enlisted aerospace experts and stakeholders to participate in numerous studies that led to the Agency's selection of the SLS architecture in September 2011. Results of those trade studies are detailed in the "Preliminary Report Regarding NASA's Space Launch System and Multi-Purpose Crew Vehicle Pursuant to Section 309 of the NASA Authorization Act of 2010 (P.L. 111-267)" [2].

Based on requirements for a safe, affordable, and sustainable capability, a Shuttle-derived design was found to offer the safest, most-capable transportation system in the shortest amount of time for the anticipated near-term and long-range budgets. The SLS operational scheme takes advantage of resources established for the Space Shuttle, including the workforce, tooling, manufacturing processes, supply chains, transportation logistics, launch infrastructure, and LOX/LH2 propellants.

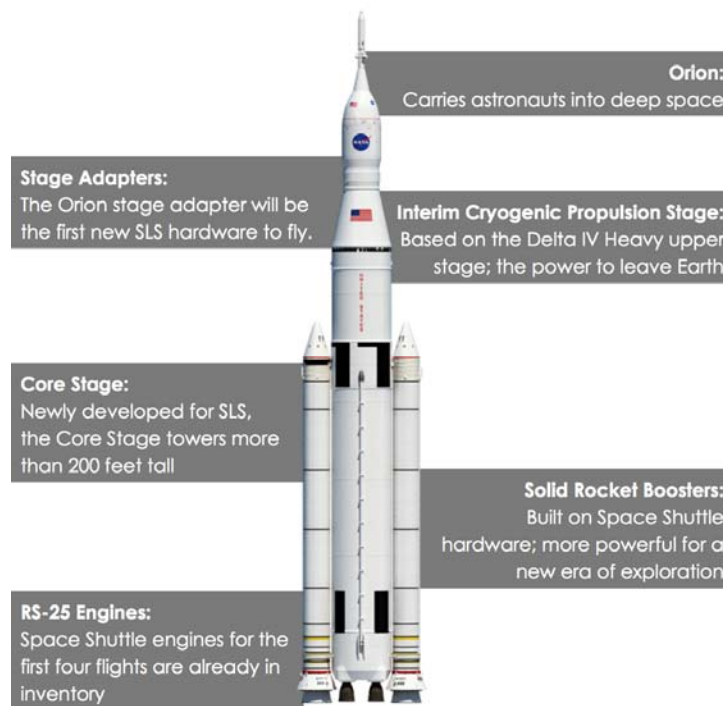


Fig. II. Overview of the Space Launch System design.

The core stage is the only major new development in the SLS acquisition plan. The massive 8.4-m-diameter, 61-m-tall tank that forms the rocket's structural backbone is being built by the Boeing Company at Michoud Assembly Facility, where the Saturn stages and Shuttle external tanks were manufactured. The stage, made of Aluminum 2219, will hold the LOX/LH2 propellants for the vehicle's main engines. The core stage also contains the instrument ring, which houses the vehicle-level avionics. Currently, over 200 design drawings are being released per month. The core stage CDR is slated for mid-2014. All avionics components have completed their PDRs, with some having completed CDR. Confidence welding began in mid-2013 at Michoud on core stage barrel sections. In 2015, the avionics will be shipped to MAF for integration into the stage, where the RS-25 engines will also be integrated. The integrated stage is due to be delivered to KSC for launch processing in late 2016/early 2017.

The SLS Core Stage will be powered by four RS-25 engines, which previously served as the Space Shuttle Main Engine, taking advantage of 30 years of U.S. experience LOX/LH2, as well as an existing national infrastructure that includes specialized manufacturing and launching facilities. These human-rated engines support the SLS goal of

safety, with a record of 100 percent mission success for the engines over 135 flights. At the end of the Space Shuttle Program, 16 RS-25 engines were transferred to the SLS Program and placed in inventory at NASA's Stennis Space Center, providing enough engines for the first four flights of SLS. The RS-25 main engine delivers more than 500,000 pounds of thrust at 109 percent rated power level. Produced by Aerojet Rocketdyne, the RS-25 is the first reusable rocket engine in history, as well as the most reliable and highly tested large rocket engine ever built. During the 30-year Space Shuttle era, the RS-25 achieved 100 percent mission success with a demonstrated reliability exceeding 0.9996. During 135 missions and related engine testing, the RS-25 system accumulated over 1 million seconds of hot-fire experience.

The majority of the thrust at launch for SLS will come from a pair of solid rocket boosters, also of Space Shuttle Program heritage, but upgraded = from the four-segment version flown on the Shuttle to a more-powerful five-segment version. The 5-segment SRBs for 70 t SLS configuration are produced by Alliant Techsystems, Inc. (ATK) and will be the most powerful in the world, delivering 3.55 million pounds of thrust during the early boost phase of flight. Heritage hardware and design includes forward structures, metal cases, aft skirt, and thrust vector control. The upgraded hardware and expendable design includes the solid rocket motor, avionics, and asbestos-free insulation.

The first original SLS Program flight hardware to be completed is the Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA), a structural ring that will mate an Orion pathfinder to a Delta IV rocket for an Earth orbit test flight in 2014. Reflecting the SLS Program's "design once, build many times" affordability tenet, this same design will be used for full-up SLS missions. The MSA is an in-house development for the Exploration Flight Test in 2014, and is currently at Kennedy Space Center awaiting launch.

In-space propulsion for the 70 t Block 1 version of SLS will be provided by the Interim Cryogenic Propulsion Stage (ICPS), derived from United Launch Alliance's Delta Cryogenic Second Stage (DCSS) flown on more than 20 launches of the Delta IV Evolved Expendable Launch Vehicle (EELV).

III. VEHICLE EVOLUTION

While the SLS Program is primarily focused on first flight, early development work has already begun for evolution of SLS beyond the 70 t Block 1. Reaching the full 130 t Block 2 capability will supplement the architecture developed for the initial configuration with two major new developments (Fig. III). The SLS evolution approach makes it possible to fly an interim 105-t-class vehicle after the completion of the first of those upgrades. The 105-ton vehicle has been identified as fitting a potential "sweet spot" for the next set of human missions beyond LEO.

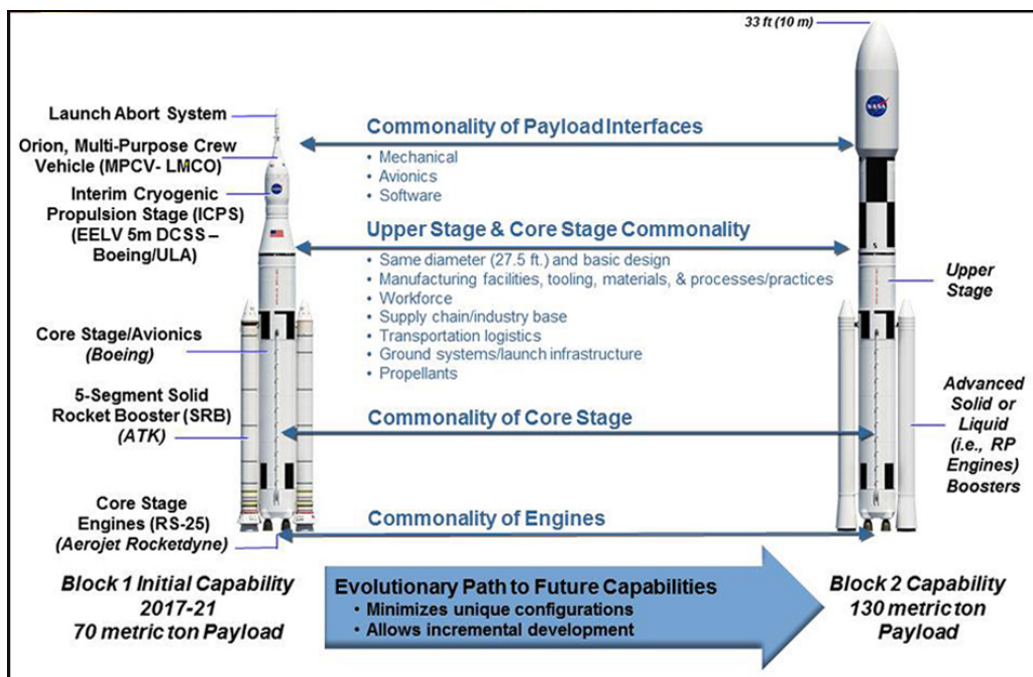


Fig. III. SLS commonality-based evolution approach.

Conceptual development and risk reduction work has already begun advanced boosters that will provide a thrust advantage over the Shuttle-heritage solid rocket boosters. This requirement provides a competitive opportunity for industry to deliver cost-effective, innovative hardware solutions. Through the Advanced Booster Engineering Demonstration and Risk Reduction task, contracts were awarded beginning in 2012 to four industry teams to perform tasks that could later inform the selection of a design for SLS advanced boosters. One of the contracts, awarded to ATK, involves research into propellant mixes and composite materials for advanced solid rocket boosters. The other three contracts, awarded to Northrop Grumman, Aerojet Rocketdyne, and Dynetics, focus on a combination of structures and engines for liquid hydrocarbon fuel boosters. At the same time, research is being conducted into upper stage options for the vehicle. Current plans call for a dual-use Exploration Upper Stage for ascent and in-space propulsion, which would enable greater mission capture on an early timeline by reducing the number of new developments required.

Both the initial and evolved configurations of SLS have the capability to conduct cargo launches using a payload fairing. The vehicle is capable in the near-term of supporting cargo launch using existing industry 5 meter fairings, providing a payload environment compatible with extant launch vehicles, but with higher characteristic energy (C3) and greater mass margins. Early research has also been conducted into options for larger 8.4- and 10-m fairings, with which SLS would offer greater payload volume lift capability than any other launch vehicle.

IV. HUMAN SPACEFLIGHT UTILIZATION

The Space Launch System was authorized with the intent of providing an enabling capability for human exploration into deep space, including, but not limited to, the eventual goal of landings on Mars. For missions beyond cislunar space, SLS will be one of several new system developments that will be required. By investing in the launch vehicle as the first development, NASA will enable test flights and near-term exploration—and potentially game-changing robotic science missions and uniquely large space hardware—while the other systems are being developed concurrently.

For human missions, SLS will launch the Orion MPCV, designed for beyond-Earth-orbit human spaceflight, with such supporting capabilities as a thermal protection system designed for high-velocity Earth-atmosphere reentry from deep space. SLS is uniquely to provide the mass-lift needed to launch Orion on these missions. Plans currently under evaluation call for the first flight of SLS to send an uncrewed Orion MPCV into lunar distant retrograde orbit (DRO) This trajectory would support NASA's plans for carrying out a robotic asteroid redirection mission to move a small asteroid into lunar DRO where astronauts could rendezvous with it. Plans are for the second launch of an Orion spacecraft on SLS would be for a crewed mission along the same trajectory.

Beyond cislunar in-space missions, options exist for furthering exploration towards Mars. A flexible path represents a different type of exploration strategy, one that would allow humans to learn how to live and work in space, to visit small bodies, and to work with robotic probes on planetary surfaces. It would provide the public and other stakeholders with a series of interesting "firsts" to keep them engaged and supportive. Most important, because the path is flexible, it would allow for many different options as exploration progresses. SLS is intended to serve as a key cornerstone of the flexible path approach to space exploration, and the SLS architecture and block design approach reflect this strategy. [3]

The International Space Exploration Coordination Group (ISECG), consisting of 12 space agencies, including NASA, from nations around the world, has identified three primary "mission themes" for precursors towards human missions to the surface of Mars, enable earlier exploration while working toward the goal of the Red Planet. Those themes, as outlined in the Global Exploration Roadmap (GER), are exploration of a near-Earth asteroid, extended duration crew missions in the lunar vicinity, and humans to the lunar surface.[4] The first two would involve sending humans farther into space than they have ever been before and would require the development of the in-space systems, such as habitation and propulsion, that will eventually be needed for humans to travel through space to get to Mars. The latter theme would involve establishing a long-term human presence on the lunar surface, and would require the development of surface systems, including surface habitats and power-generation systems that

will be needed for human exploration of the surface of Mars. GER recognizes SLS as an enabling resource for its mission themes.

Design of SLS as an enabling capability for human missions to Mars was based on meeting the requirements outlined in NASA's Mars Design Reference Architecture 5 (DRA5) study of options for human Mars exploration. [5] The study outlines the systems and supplies that will be needed to execute a crewed Mars landing and identifies the Earth-orbit-departure mass for those payloads as being approximately 825 metric tons, double the mass of the International Space Station. Among the largest single systems required will be the in-space propulsion, for which the DRA5 identifies multiple options, including traditional chemical, nuclear thermal, nuclear electric, and solar electric propulsion, any of which would require the mass- and volume-lift capability provided only by an evolved SLS, with a minimum mass-lift requirement of 105 t and a minimum volume lift capability of a 10 m fairing. SLS also enables a reduced number of launches, thereby decreasing mission risk and hardware complexity.

Private entities have also begun identifying enhancing or enabling capabilities of SLS for human operations and exploration. Inspiration Mars, an organization working toward a crewed flyby of Mars, has identified SLS as an enabling requirement for that mission, and Bigelow Aerospace has likewise identified enabling benefits of SLS for the potential utilizations of the company's inflatable space habitats.

V. ROBOTIC SCIENCE UTILIZATION

While designed around the goal of enabling human exploration of the solar system, the mass and volume lift capability Space Launch System will provide to fulfill that charter will also provide game-changing benefits for a range of promising space science missions.

Primary advantages of SLS for robotic science missions include:

- Volume and mass capability and less-complex payload designs needed to fit in the fairing, leading to increased design simplicity.
- Fewer deployments and critical operations, leading to increased mission reliability and confidence.
- High-energy orbit and shorter trip times, leading to less expensive mission operations and reduced exposure to the space environment.
- Increased lift capacity and payload margin, resulting in less risk.

NASA's Marshall Space Flight Center's Advanced Concepts Office performed an SLS Utilization Study, conducted as a follow-on to earlier Constellation-era decadal surveys, astronomy workshops, and planetary workshops, investigated arenas of opportunity that extend beyond human exploration goals into other areas of space exploration. [6] The initial process of the study was to perform a literature survey of all potential arenas in order to identify key mission goals and objectives. Among the candidates identified in that study was returning a sample from the surface of Mars, which has been a long-term goal for the Mars program for some time. A 2011 National Research Council (NRC) planetary science Decadal Survey concluded that a Mars Sample Return (MSR) mission is not only a top science priority, but also a good opportunity to blend the science and human spaceflight elements of NASA.[7] The Mars Program Planning Group (MPPG) has recognized that the SLS may provide a "single shot" MSR opportunity. An SLS-enhanced Mars sample return could also be executed as a two-launch effort in connection with the Mars 2020 rover project, which is planned to cache material samples for future retrieval. A baseline approach to retrieval would require two additional launches, one to bring the samples from the surface to Martian orbit, and another to return them from orbit to Earth. SLS could combine those two launches into one, expediting the sample return and increasing the probability of mission success.

Since the completion of the SLS Utilization Study, the Program has worked with the NASA science community to further refine concepts and requirements for some of the identified missions and to discuss opportunities for future collaboration. One such mission is an advanced-technology large-aperture space telescope. Concept evaluation has demonstrated potential benefits of a large 8.4- or 10-m SLS payload fairing, which would enable the launch of a large aperture telescope that would be able to make spectroscopic observations of exoplanets, enabling a search for life in other solar systems.

Another mission that has been the subject of further concept definitization with the science community is the Europa Clipper pre-project. Jupiter's moon Europa is believed to have a subsurface ocean, covered by a layer of water ice, that contains twice as much water as Earth, making the Jovian moon a high-interest target in the search for signs of past or present life on other worlds, and a high priority of the planetary science Decadal Survey. Collaborative evaluation has revealed that by enabling a direct trajectory outbound flight to the Jovian system versus a Venus-Earth-Earth gravity assist (VEEGA) trajectory required by a baseline EELV approach, SLS could reduce transit time from more than 6 years to under 3 years.

VI. SUMMARY

Through the development and operation of the Space Launch System, NASA is creating a new international capability that will serve as a cornerstone for a wide variety of utilization of space for decades to come, complementing contemporary systems for human operations in low Earth orbit by enabling ambitious missions that would not otherwise be possible. Following its first flight, SLS will return humans to deep space for the first time in decades, beginning a series of exploration missions that will lead to Mars. That same capability will also enable a wide variety of other missions, including science spacecraft that will reveal an unprecedented wealth of knowledge about our solar system and universe.

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BIOGRAPHY

Stephen Creech is the Assistant Program Manager for Strategy and Partnerships for the Space Launch System Program, located at NASA's Marshall Space Flight Center in Huntsville, Alabama, where he leads business development, collaboration, and partnerships. He previously served as the Ares V integration manager, and managed the Engineering Cost Group in the Office of Strategic Analysis and Communications at the Marshall Center.



Mr. Creech holds a bachelor's degree in Industrial Engineering from Mississippi State University. Honors include NASA's Medal for Exceptional Service and Distinguished Performance Award and the agency's prestigious Silver Snoopy, awarded by the Astronaut Office for professionalism, dedication and outstanding support that greatly enhanced space flight safety and mission success.